Chapter 18

Vision and Hearing

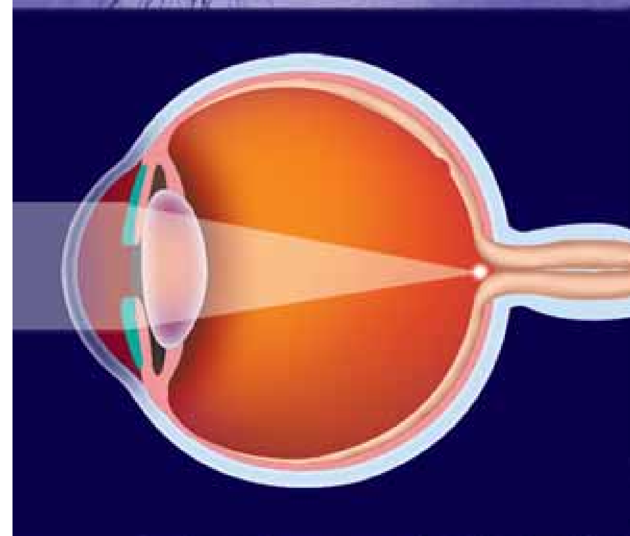
Although small, your eyes and ears are amazingly important and complex organs. Do you know how your eyes and ears work? Scientists have learned enough about these organs to begin creating artificial eye and ear parts that might restore vision and hearing to some people who have lost their ability to see or hear. To do this, scientists and engineers must know a lot about light and sound waves, as well as how the brain works. Study this chapter to learn all about light and sound waves, the brain, and even how different optical systems work in addition to the structure and function of eyes and ears.

Key Questions

1. ***What are the components of your nervous system?***

2. ***How do telescopes and human eyes work?***

3. ***How does the human ear work, and why can you tell one voice from another, even when both say the same word?***



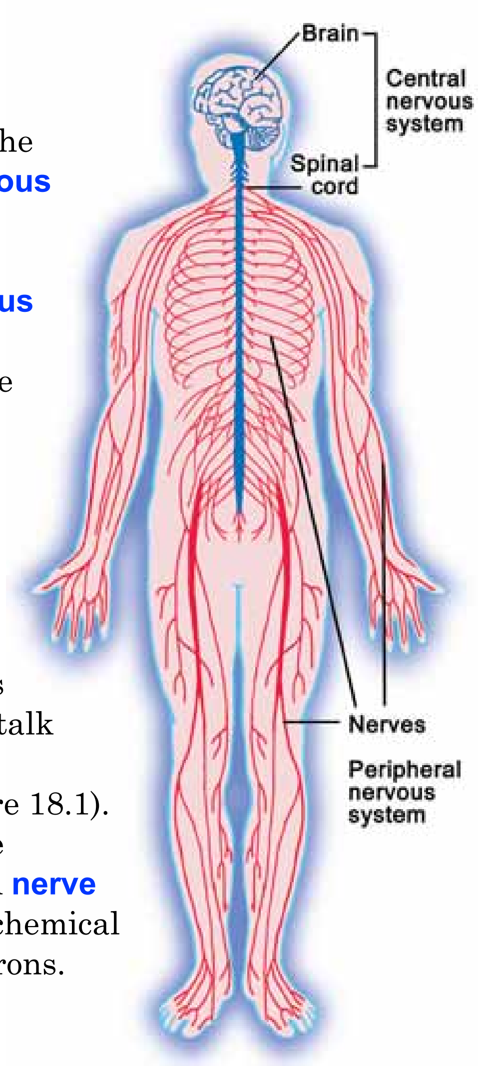
18.1 The Nervous System

Which body system allows you to see and hear? Which body system keeps your other systems working properly? You are right if you guessed your nervous system. In this section, you will learn about the components of the nervous system and how signals are transmitted in your body.

Parts of the human nervous system

Central and peripheral nervous systems There are two major divisions of the nervous system. The **central nervous system** is your body's command center. It includes the brain and spinal cord. The **peripheral nervous system** consists of nerves that connect all areas of the body to the central nervous system. You can think of the peripheral nervous system as the "information highway" of your nervous system.

Neurons and nerve impulses Your nervous system is made of hundreds of billions of specialized cells called neurons. A neuron has three parts: the cell body, a long stalk called the axon, and finger-like projections called dendrites (Figure 18.1). Neurons send signals called nerve impulses throughout your body. A **nerve impulse** is wave of electrical and chemical activity transmitted between neurons.



VOCABULARY

central nervous system - the control center of the body that includes the brain and spinal cord.

peripheral nervous system - consists of nerves that connect all areas of the body to the central nervous system.

nerve impulse - a wave of electrical activity transmitted between neurons.

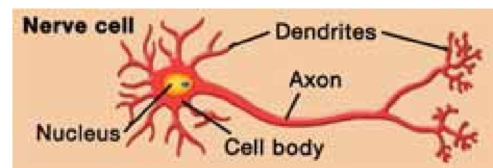


Figure 18.1: *The parts of a neuron.*

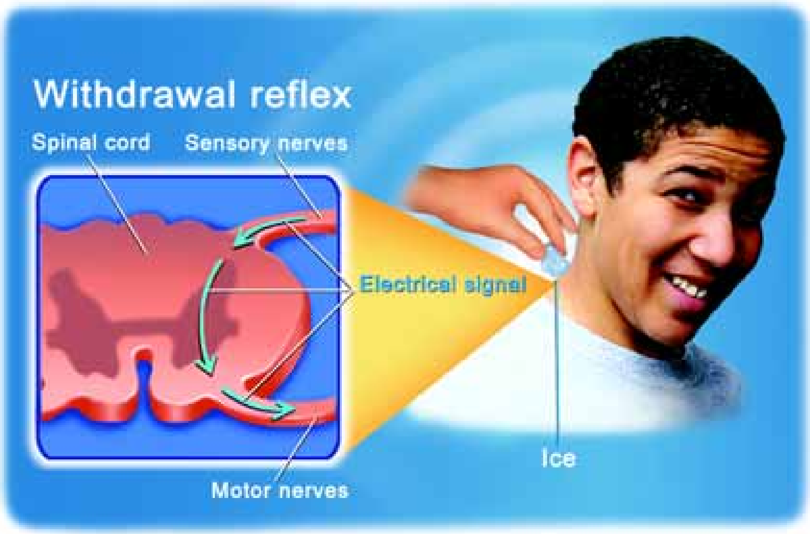
How your body responds to a stimulus

The withdrawal reflex

Imagine you're relaxing on the couch, watching your favorite television show. Someone sneaks up behind you and touches the back of your neck with a wet, frosty ice cube. Before you even have a chance to think "who did that?" your body springs into action. The ice cube triggers an automatic response called a **withdrawal reflex** that happens without a conscious decision on your part.

Sensory and motor nerves

A withdrawal reflex happens because nerve impulses are sent through the nerves in your body. When an ice cube touches the back of your neck, **sensory nerves** in your skin send nerve impulses through wire-like nerve fibers to your spinal cord. In the spinal cord, the nerve impulse is transferred to motor nerves. **Motor nerves** control muscle contractions. Impulses from your motor nerves cause the muscles in your neck and back to contract, jerking your body away from the ice cube. All of this happens in a split second!



VOCABULARY

withdrawal reflex - an involuntary response to an outside stimulus.

sensory nerves - nerves that receive sensory stimuli, such as how something feels.

motor nerves - nerves that transmit signals to skeletal muscle, causing movement.

MY JOURNAL

A withdrawal reflex happens automatically. A stimulus like cold or hot can trigger this response. Write a reflection about a time you experienced a withdrawal reflex. What caused the withdrawal reflex (the stimulus)? How did your body respond? How did you react afterwards?

How a nerve impulse works

Electrical and chemical signals

A withdrawal reflex starts when sensory nerves in your skin receive a stimulus from outside the body. That stimulus starts a nerve impulse along the cell membrane. When a neuron is at rest, the inside of the cell membrane is electrically negative compared with the outside. Figure 18.2 illustrates how a nerve impulse works.

1. The stimulus causes the cell membrane to open channels that let positively-charged particles into the cell. The inside of the cell becomes positively charged compared with the outside.
2. Other channels open and let positively-charged particles out of the cell. As they leave, the inside of the cell membrane once again becomes negatively-charged compared with the outside.
3. The nerve impulse travels down the axon like dominoes falling. When the impulse reaches the end of the axon, chemicals are released and picked up by a neighboring neuron, causing the nerve impulse to continue.

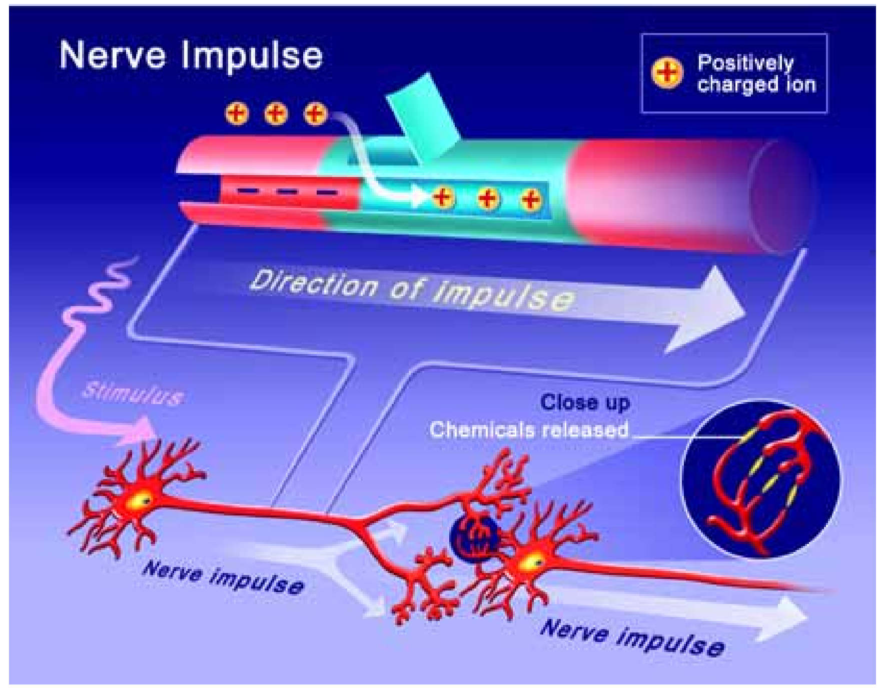


Figure 18.2: *A nerve impulse is a combination of electrical and chemical signals.*

Non-stop nerve impulses

Each second, your body fires off about five trillion nerve impulses. **Your emotions, decisions, and physical actions all happen through nerve impulses traveling through neurons in your brain, spinal cord and nerves.** A single neuron can have up to ten thousand dendrites connecting to other neurons. It is estimated that just one cubic millimeter of brain tissue contains a billion connections between cells!

The brain

What is the brain? The brain is the processing and control center of your nervous system. The brain and spinal cord are made of tissues called gray and white matter. *Gray matter* is mostly made up of the cell bodies of neurons. *White matter* is mostly made up of the axons coming from those cell bodies. In general, grey matter makes up the parts of the brain responsible for information processing. White matter is responsible for transmitting nerve impulses.

The brain has three parts The three parts of the brain are the cerebrum, the cerebellum, and the medulla (Figure 18.3). These parts are all connected but each part has its own function.

The cerebrum The largest part of your brain is the dome-shaped cerebrum. The **cerebrum** controls voluntary movements and the senses (touch, taste, smell, vision, hearing). It also allows you to think, talk, solve problems, and imagine. The cerebrum is divided into two halves called hemispheres. The right hemisphere controls the left side of the body and the left hemisphere controls the right side of your body! But both sides are involved in most activities.

The cerebellum The **cerebellum** provides feedback on the position of the body in space. It receives sensory information and sends nerve impulses to different skeletal muscles to keep you balanced. The cerebellum is located underneath the back of your cerebrum.

The medulla The **medulla** is the part of the brain that controls your spinal cord. It also controls your involuntary breathing, heart rate, blood pressure, and some other involuntary activities. It receives sensory input from the heart and blood vessels and sends nerve impulses back to those organs to control their function. The medulla is located underneath the cerebrum and in front of the cerebellum.

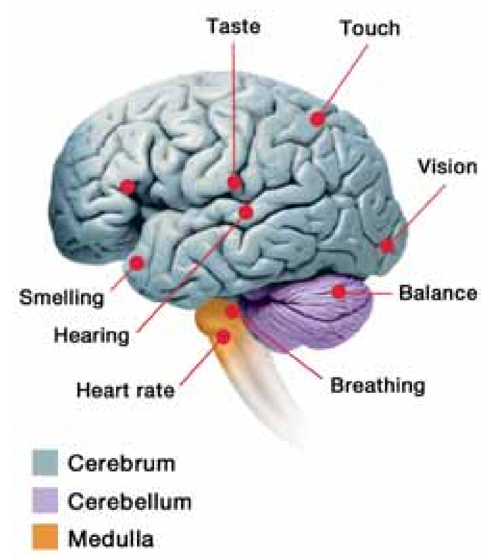


Figure 18.3: *The three parts of the brain and some of their functions.*

VOCABULARY

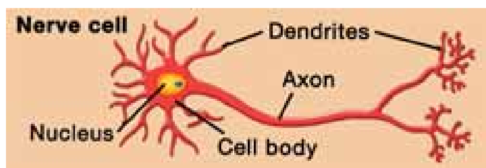
cerebrum - the part of the brain that controls voluntary movements, the senses, and thought.

cerebellum - the part of the brain that keeps the body in balance.

medulla - the part of the brain that controls the spinal cord and many involuntary activities like breathing and heart rate.

18.1 Section Review

1. Define each category of the nervous system:
    a. central nervous system
    b. peripheral nervous system
2. Explain how a nerve impulse is both electrical and chemical.
3. Classify each as voluntary, involuntary, or both. If the action can be both, explain how.
    a. the beating of your heart muscle
    b. breathing
    c. raising your arm
    d. lifting a rock
    e. blinking your eyes
    f. movement of muscles in your digestive system
4. The diagram below shows a neuron. Name the function of each of its parts.



5. The brain and spinal cord are made of two tissues. Name those tissues and explain their function.
6. Match each brain structure to one of its functions.

Structure	Function
1. medulla	a. controls involuntary breathing
2. cerebrum	b. detects the position of the body in space
3. cerebellum	c. controls imagination

CHALLENGE

Measuring how fast someone responds to what they see

1. Hold a ruler near the end (highest number) and let it hang down.
2. Have a partner put their hand at the bottom of the ruler and ready to grab it. They should not be touching the ruler.
3. Tell your partner that you will drop the ruler sometime within the next 5 seconds. They should catch the ruler as fast as they can after it is dropped.
4. Record the place on the ruler where they catch it, in cm.
5. Test the same person 3 to 5 times. Vary the time of dropping the ruler within the 5 second "drop-zone" so the other person cannot guess when you will drop the ruler.
6. Design an experiment to test one of the following questions:

- Does the amount of light affect response?
- Who responds faster, girls or boys?
- Does age affect response?

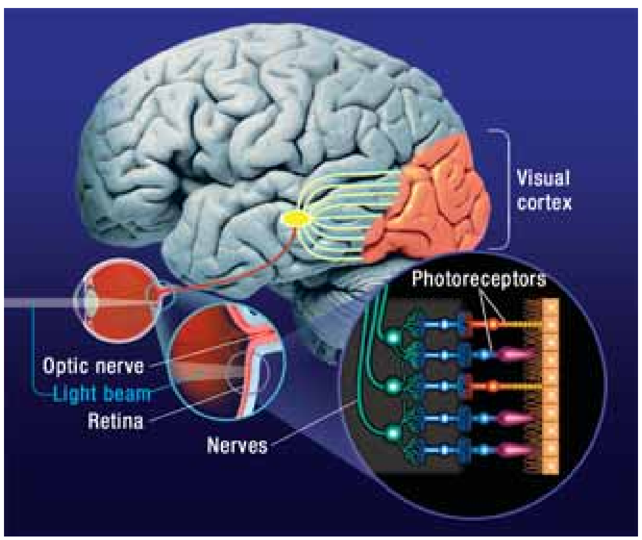
18.2 Vision

In Chapter 4, you learned how a microscope uses light to form magnified images. The human eye also uses light to form images. Every time you see something, light is involved. In complete darkness, you cannot see anything! In this section, you will explore how human vision works.

The human eye

You see the world by reflected light Figure 18.4 shows what happens when you see this page. Light rays in the room reflect off the page and into your eyes. The reflected light carries information that allows your brain to form an image of the page. If you were in a room with no light, you would not be able to see this page because it does not give off its own light. You see many objects because they reflect light

How the eye works The *eye* is the sensory organ used for vision. You learned about the mammalian eye in Chapter 15. The structures of the human eye are similar to the eyes of other mammals.



Light passes through the cornea and enters the eye through the pupil. It passes through the lens and is refracted to a focal point on the retina.

The retina contains light-sensitive cells called photoreceptors. **Photoreceptors** convert light into nerve impulses that travel through the **optic nerve** to the visual cortex of the brain. The *visual cortex* interprets the light as an image.

STUDY SKILLS

Review Section 4.3 to refresh your memory about light. Write down the following terms and their meanings: **light ray, reflection, refraction, lens, focal point, focal length.**

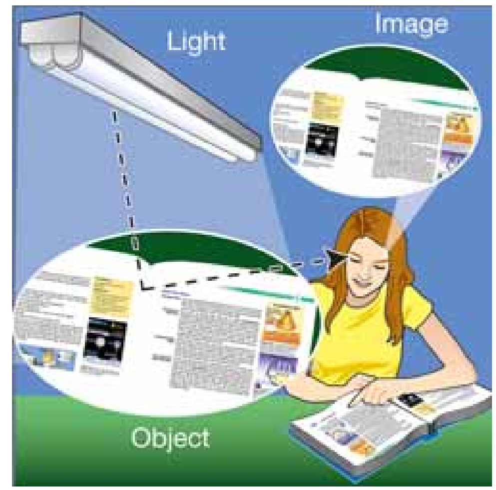


Figure 18.4: *What happens when you see this page.*

VOCABULARY

photoreceptors - light-sensitive cells of the retina that convert light into nerve impulses.

optic nerve - a nerve that carries nerve impulses from the eyes to the brain.

Seeing an image

How does light enter the eye?

Light enters the eye through the pupil. The **pupil** is an opening created by the *iris*, the pigmented part of the eye. A ring of muscles causes the iris to open or close to change the size of the pupil. When there is a lot of light, the iris closes and pupil gets smaller. When the light is dim, the iris opens up and the pupil gets larger (Figure 18.5).

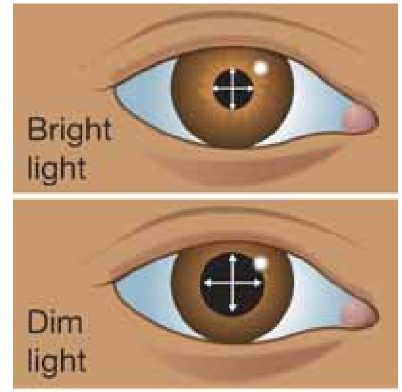
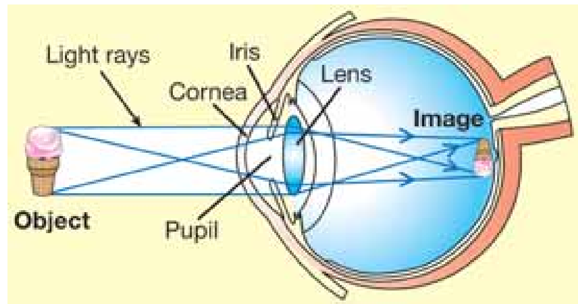


Figure 18.5: *The pupil of the eye gets smaller in bright light and larger in dim light.*

The lens forms an image

An **image** is a picture of an object formed where light rays meet. In Chapter 4 you learned that a convex lens refracts light rays to a focal point. The lens in your eye refracts light rays to a focal point on the retina called the fovea. The *fovea* is the spot on the retina where the image forms. Since the lens in your eye is a single lens, the image formed on the retina is actually upside down! Your brain interprets the image as right-side up so you don't notice.



Focusing

The lens in your eye has a feature that makes it different from the lenses you use in a science lab. The lens in your eye is flexible. Small muscles around the edge cause the lens to stretch and change its shape. When the lens changes its shape, so does the focal length. This allows you to focus on objects close by and also on objects further away (Figure 18.6). The *cornea* is the transparent front part of the eye that covers the iris and pupil. The cornea works with the lens to refract light and helps the eye to focus. But unlike the lens, the curvature of the cornea is fixed.

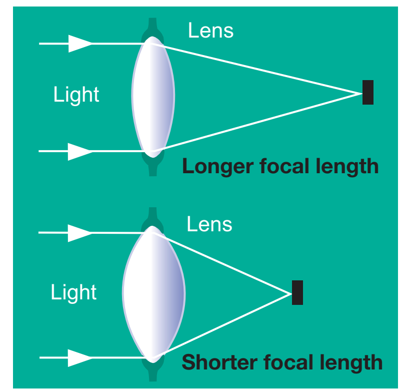


Figure 18.6: *The lens of your eye can change shape to change its focal length.*

VOCABULARY

pupil - the hole in the eye through which light enters.

image - a picture of an object formed where light rays meet.

How the human eye sees color

How we see color

In Chapter 6, you learned that **light is part of a range of waves called the electromagnetic spectrum. *Color* is how we perceive the energy of light**. All of the colors of visible light have different energies. Red light has the lowest energy and violet light has the highest energy. As you move through the spectrum of visible light from red to violet, the energy of the light increases (Figure 18.7).

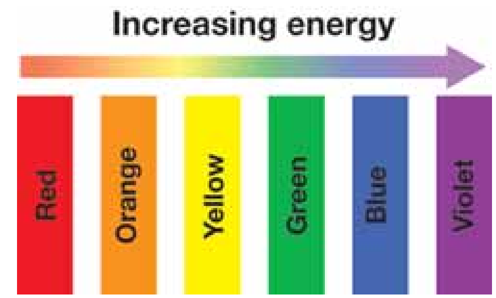


Figure 18.7: *Color is how we perceive the energy of light.*

Cone cells respond to color

Our eyes have two types of photoreceptors: cone cells and rod cells. **Cone cells** respond to color (Figure 18.8) and there are three types. One type responds best to red light. Another type responds best to green light and the last type responds best to blue light. We see a wide range of colors depending on how each kind of cone cell is stimulated. For example, we see white light when all three types of cones (red, green, blue) are equally stimulated.

Rod cells respond to light intensity

Rod cells respond only to differences in light intensity, and not to color (Figure 18.8). Rod cells detect black, white, and shades of gray. However, rod cells are more sensitive than cone cells especially at low light levels. At night, colors seem washed out because there is not enough light for cone cells to work. When the light level is very dim, you see "black and white" images transmitted from your rod cells.

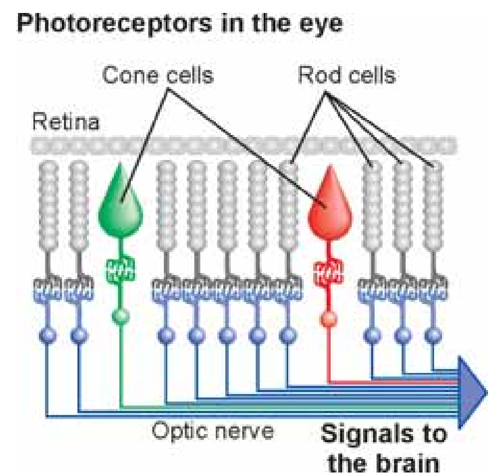


Figure 18.8: *Cone cells and rod cells.*

How rod and cone cells work together

An average human eye contains about 130 million rod cells and 7 million cone cells. Each one contributes a "dot" to the total image assembled by your brain. The brain evaluates all 137 million "dots" about 15 times each second. The cone cells are concentrated near the center of the retina, making color vision best at the center of the eye's field of view. Each cone cell "colors" the signals from the surrounding rod cells.

VOCABULARY

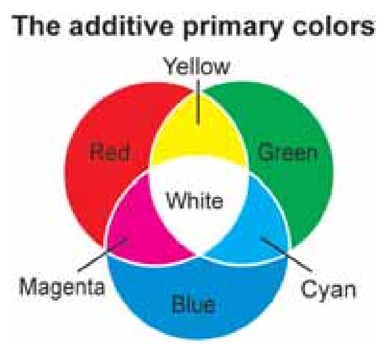
cone cells - photoreceptors that respond to color

rod cells - photoreceptors that respond to light intensity.

How color is perceived

The additive color process Our eyes work according to an *additive color process* — three photoreceptors (red, green, and blue) in the eye operate together so that we see millions of different colors. The color you "see" depends on how much energy is received by each of the three different types of cone cells. The brain thinks "green" when there is a strong signal from the green cone cells but no signal from the blue or red cone cells (Figure 18.9).

How we perceive color We perceive different colors as a combination of percentages of the three additive primary colors: red, green, and blue. For example, we see yellow when the brain gets an equally strong signal from both the red and the green cone cells at the same time. Whether the light is actually yellow, or a combination of red and green, the cones respond the same way and we perceive yellow. If the red signal is stronger than the green signal we see orange (Figure 18.10). If all three cones send an equal signal to the brain, we interpret the light we see as white.



Two ways to see a color The human eye can see any color by adding different percentages of the three additive primary colors. Mixing red and green light is one way the eye sees the color yellow or orange, for example. Keep in mind that you perceive these colors even though the light itself is still red and green. You can also see pure yellow light or orange light that is not a mixture of red and green. For example, sodium street lights produce pure yellow light, not a mixture of yellow and green.

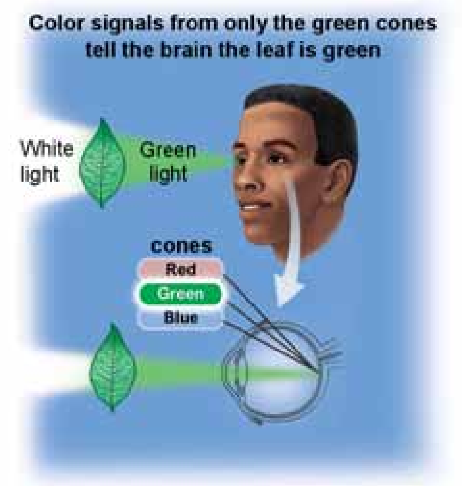


Figure 18.9: *If the brain gets a signal from only the green cone, we see green.*

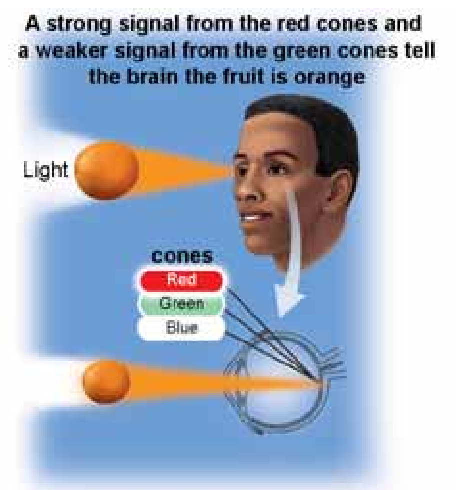


Figure 18.10: *If there is a strong red signal and a weak green signal, we see orange.*

Color blindness

Not everyone sees color the same way You may be surprised to learn that all people do not see color the same way. A condition called color blindness affects about 8 percent of males and 0.4 percent of females. This means that about one out of every 13 men has color blindness and about one out of every 250 women has color blindness.

Color blindness is inherited Although color blindness can be caused by eye disease, it is most often an inherited condition. More males than females have color blindness because of how the genes that determine our sex are inherited. Males have a X and a Y chromosome; females have two X chromosomes. The color blindness alleles are on the X chromosome which males receive only from their mothers; they receive the Y chromosome from their fathers. Because females receive two X chromosomes, they have two chances to inherit the alleles for normal color vision.

What is color blindness? People who are color blind have trouble seeing certain colors. The most common condition is red-green color blindness (Figure 18.11). People with this type of color blindness have trouble seeing reds and greens. Less common is blue-green color blindness. Complete color blindness means that the person can only see shades of gray. Fortunately, this condition is rare.

Living with color blindness It is easy to lead a normal life with color blindness. Having color blindness just means that an individual must look for ways to adapt to situations where color is involved. For example, color is extremely important when driving because traffic lights and street signs are color-coded. Fortunately, in most states, the traffic lights are vertical and the colors are in the same position—red on top, yellow in the center, and green on the bottom.

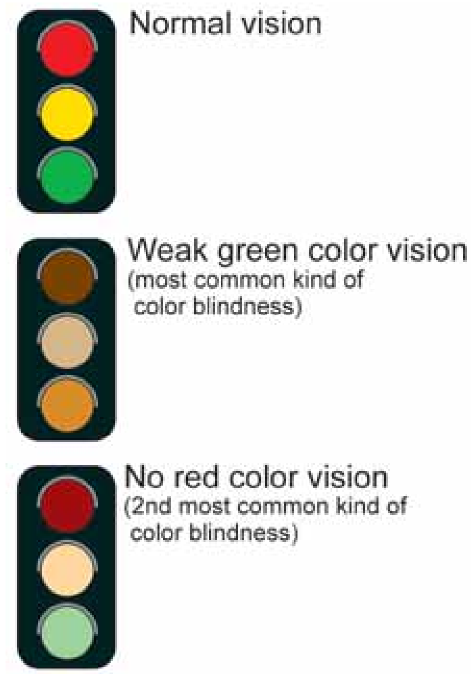


Figure 18.11: *This graphic illustrates how red-green color blindness affects seeing a traffic light. The top of the graphic shows what the traffic light looks like with normal color vision. The middle and bottom graphic show what a traffic light looks like with two of the common forms of color blindness.*

18.2 Section Review

1. Match the parts of the eye to their functions:

Structure	Function
1. iris	a. hole through which light enters
2. cornea	b. opens or closes to change the pupil
3. lens	c. respond to light intensity
4. retina	d. convert light into nerve impulses
5. photoreceptors	e. refracts light and can change shape
6. optic nerve	f. refracts light and helps the lens focus
7. rod cells	g. respond to color
8. pupil	h. sends nerve impulses to the brain
9. cone cells	h. inner surface where light rays land

2. Match the structures in question 1 to the letters on the diagram in Figure 18.12.
3. Fill in the table below:

Colors of light mixed	Color you see
red + green	
red + blue	
green + blue	
red + green + blue	

4. What is color blindness? Why is it more common in males than in females?

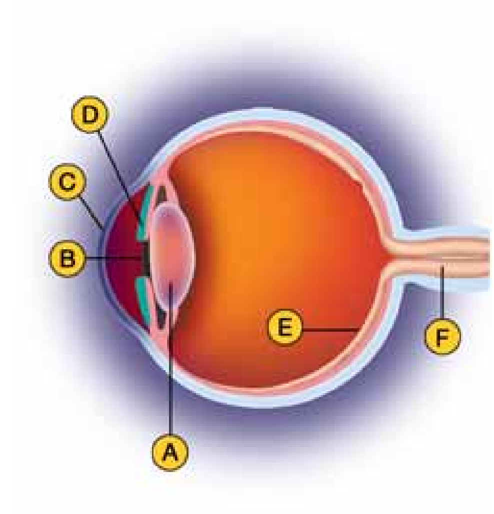


Figure 18.12: *Use the diagram above to answer question 2.*

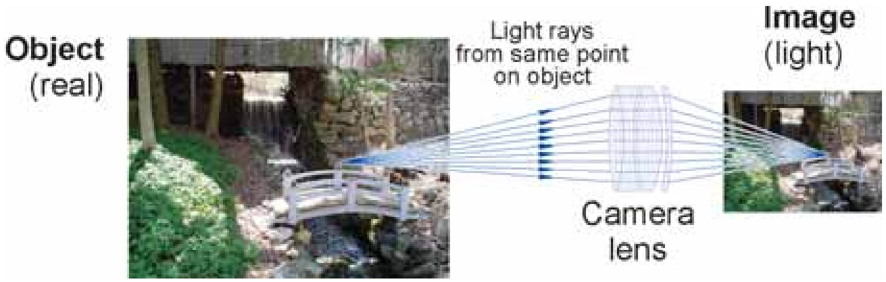
18.3 Optics

Optics is the study of how light behaves. It is helpful to think about optics in terms of *objects* and *images*. Objects are real physical things that give off or reflect light rays. Images are "pictures" of objects that are formed in space where light rays meet. Images are formed by our eyes, and by mirrors, lenses, prisms, and other optical devices (Figure 18.13). Images are not objects you can touch; they are just illusions created by organizing light collected from objects. You learned how lenses refract light in Chapter 4. In this section, you will learn about how lenses and mirrors create images.

Images

How images are created

Each point on an object gives off light rays in all directions. That is why you can see an object from different directions. Images are created by collecting many light rays from each point on an object and bringing them back together again in a single point (the *focal point*). For example, a camera works by collecting the rays from an object so they form an image on the film. In the diagram below many rays from a part of the bridge railing are focused to a single point by the camera lens, forming the image of that part of the railing. A camera captures some but not all of the light rays. This is why a photograph only shows one side of an object — you can't turn a photograph over and see the back of any object!



STUDY SKILLS

Review the following terms from Section 4.3:

lens, convex lens, concave lens, microscope

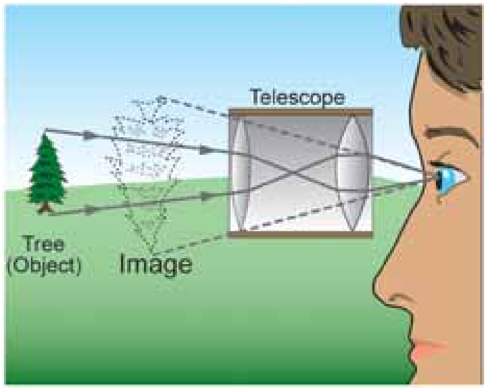


Figure 18.13: *You see the tree because light from the tree reaches your eye. The image of the tree in a telescope is not the real tree, but instead is a different way of organizing light from the tree. A telescope organizes the light so that the tree appears bigger but also upside down!*

VOCABULARY

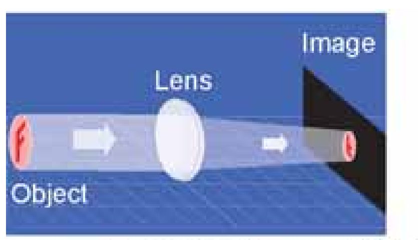
optics - the study of how light behaves.

Virtual and real images

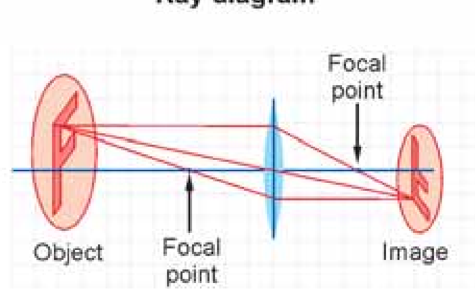
Seeing your reflection If you stand in front of a flat mirror, your image appears the same distance behind the mirror as you are in front of the mirror (Figure 18.14). If you move back the image seems to move back too. If you raise your left hand, the hand on the left side of the image is raised. How does this happen?

Virtual images The image in a mirror is called a virtual image. In a **virtual image**, light rays do not *actually* come together to a focal point to form the image. They only *appear* to come together. The virtual image in a flat mirror is created by your eyes and brain. Your brain "sees" where you would be if the light rays reaching your eye had come in a single straight line. Because the light rays do not actually meet, a virtual image cannot be projected onto a screen or on film. Virtual images are illusions created by your eye and brain.

A converging lens forms a real image A convex lens can form a real image (diagram below). In a **real image**, light from a single point on an object comes back together at a single point in another place to make an image. The place where light comes back together again is called the *focus*. The focus is where you see the image clearly. Real images can be projected onto a screen or film as shown below.



Experiment



Ray diagram

Figure 18.14: *An image in a flat mirror.*

VOCABULARY

virtual image - an image where light rays do not actually come together to form the image.

real image - light from a single point on an object comes back together at a single point in another place to make an image.

Optical systems

What is an optical system?

Optical systems are built from lenses, mirrors, and prisms. Optical systems do two things. First, an optical system collects light rays. Second, the system changes the light rays to form an image. A camera is an optical system that collects light to *record* an image. Your eye is also an optical system. A photocopy machine is another optical system. The more light an optical system collects, the brighter the image it can form.

A pinhole camera

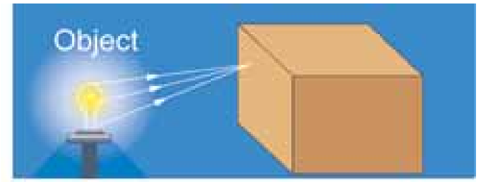
A pinhole camera is a simple optical system (Figure 18.15). You can make a pinhole camera by poking a pinhole through a box. No image forms on the front of the box because rays from many points of the object reach the same point on the box. An image does form inside the box, however. The image inside the box forms because light rays that reach a point on the box surface are restricted by the pinhole to come from only a pinhole-sized point on the object.

A lens makes the image brighter

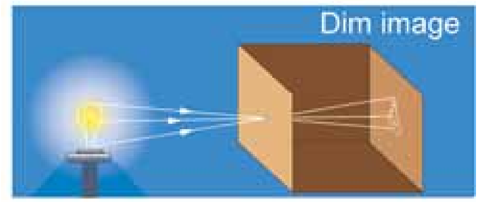
The image formed by a pinhole is very dim because the pinhole is small and does not allow much light to come through. The image formed by a lens is brighter because a lens is larger and collects more light (Figure 18.15). Each point on the image is formed by a cone of light collected by the lens. With a pinhole, the cone is much smaller and therefore the image has a much lower light intensity.

Larger lenses make brighter images

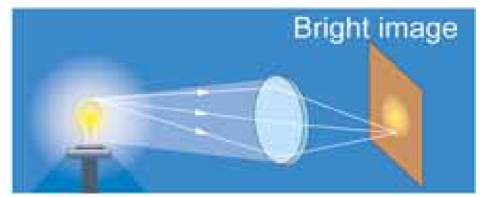
The larger the lens, the brighter the image. This is because a larger lens collects more light rays. Compared to smaller lenses, larger lenses can make good images with less light. That is why inexpensive cameras with small lenses need a flash to take pictures indoors. The small lens does not capture enough light by itself.



No image forms on the face of the box because light from many points on the object falls on the same point on the box.



A pinhole forms a dim image by restricting light from each point on the object to a single point on the back of the box.



A lens forms a bright image by focusing more light from each point on the object to the equivalent point on the image.

Figure 18.15: *The images formed by a pinhole camera and a lens are different in brightness because different amounts of light are collected to form each point in the image.*

How telescopes work

Lenses can form virtual images

In addition to real images, lenses can also form virtual images. For example, a convex lens used as a magnifying glass creates an image that is virtual and larger than life (magnified). Light is refracted by the lens so that it appears to come from a much larger object (Figure 18.16).

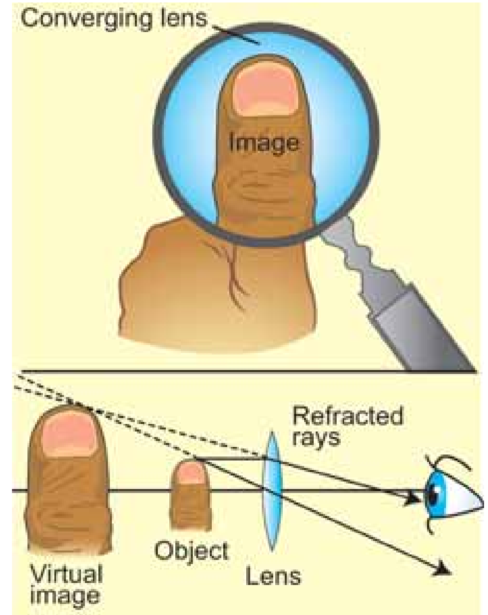


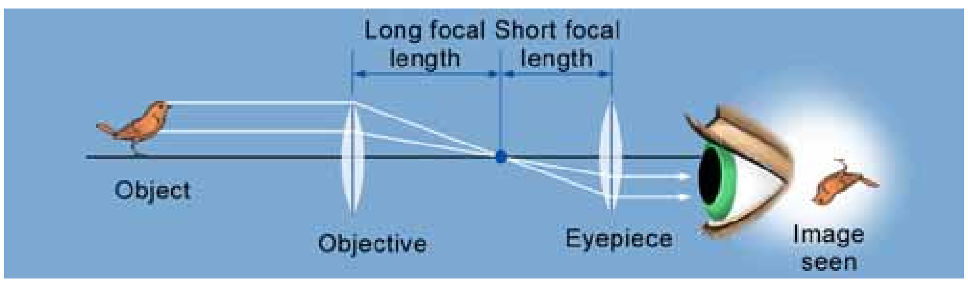
Figure 18.16: *A magnifying glass forms a virtual image that is larger and appears behind the lens.*

A magnifying glass

A magnifying glass is a single convex lens. A magnified virtual image forms when you look at an object that is *closer* than one focal length from the lens. If the object is farther than one focal length you see a real image that is smaller than actual size (and upside down). The focal-length limit is why magnifying glasses should be held fairly close to the objects you are looking at.

The refracting telescope

To get higher magnification, microscopes and telescopes use more than one lens. A *refracting telescope* has two convex lenses with different focal lengths. The lens with the shorter focal length is nearer to the eye.



Reflecting telescope

Because large lenses are nearly impossible to make, most modern telescopes use a concave mirror instead of one lens. The diagram shows a reflecting telescope, much like the one used by the Hubble Space Telescope and almost all astronomical observatories (Figure 18.17).

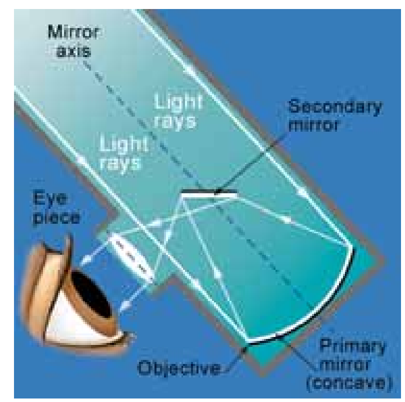
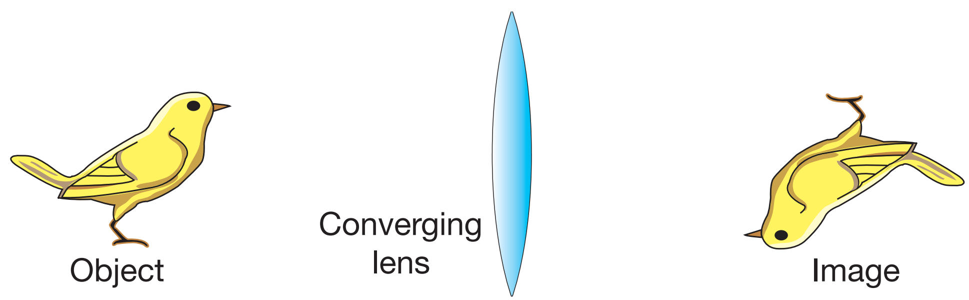


Figure 18.17: *The light rays in a reflecting telescope.*

18.3 Section Review

1. If an object is 1 foot away from a mirror, how far behind the mirror surface does the image appear to be? Is this image a real or virtual image?
2. What is the difference between a real and virtual image?
3. Mirrors and lenses both produce images your eyes can see. How are mirrors and lenses similar? How are they different?
4. Copy the diagram below on your paper. Using a ruler, draw the path of the light rays from the object to the image in the diagram below.



5. Is the image in the diagram above a virtual image or a real image? Explain your answer.
6. Why do ambulances often have the letters for "AMBULANCE" reversed on the front of the vehicle?
7. Why do some optical systems use more than one lens?
8. Explain how a lens can form both virtual and real images.
9. Is the image of the brine shrimp in Figure 18.18 a virtual image or a real image? Explain your answer.

STUDY SKILLS

Make a concept map using the following terms:

lens
refraction
reflection
light ray
optical system
eye
camera
telescope
virtual image
real image
mirror
convex lens
concave lens

Figure 18.18: *Use this picture to answer question 9.*

18.4 Hearing

Like light, sound is a wave. A **wave** is a vibration that transfers energy from place to place. Your eyes can detect light waves. You cannot see sound waves with your eyes. Instead, you "see" them with your ears! In this section, you will learn about sound and how the ear detects it.

VOCABULARY

wave - a vibration that transfers energy from place to place.

frequency - the number of vibrations per second.

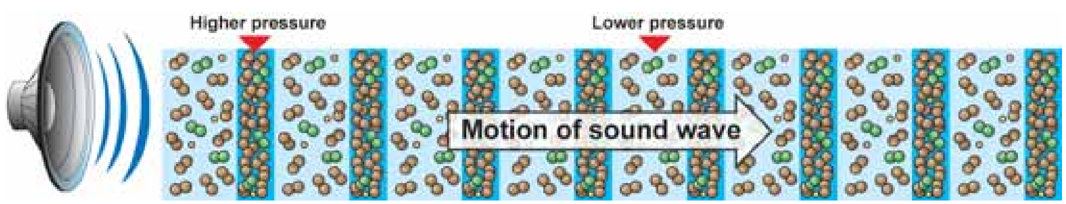
What is sound?

Sound is a wave

Sound waves are *pressure waves* with alternating high and low pressure regions. A sound wave is created when something vibrates—like a speaker playing music. If you touch the surface of the speaker, you can feel the vibrations that create a sound wave. Those vibrations transfer energy to the surrounding air molecules.

How a sound wave is created

Air molecules are spread very far apart and are in constant, random motion (Figure 18.19). When they are pushed by the vibrations, it creates a layer of higher pressure (Figure 18.20). That layer pushes on the next layer, which pushes on the next layer, and so on. The result is a traveling vibration of pressure—a sound wave. The molecules in a sound wave are compressed in the direction that the wave travels.



Frequency

The **frequency** of a sound wave is the number of vibrations per second. Wave frequency is measured in *hertz* (Hz). A wave with a frequency of 1 hertz vibrates at one vibration per second.

Figure 18.19: *Air is made of molecules in constant, random motion.*

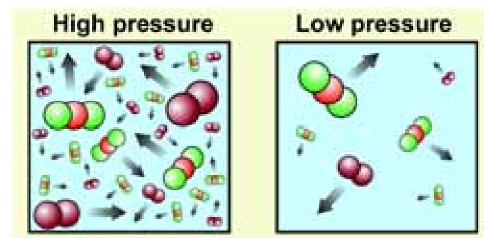
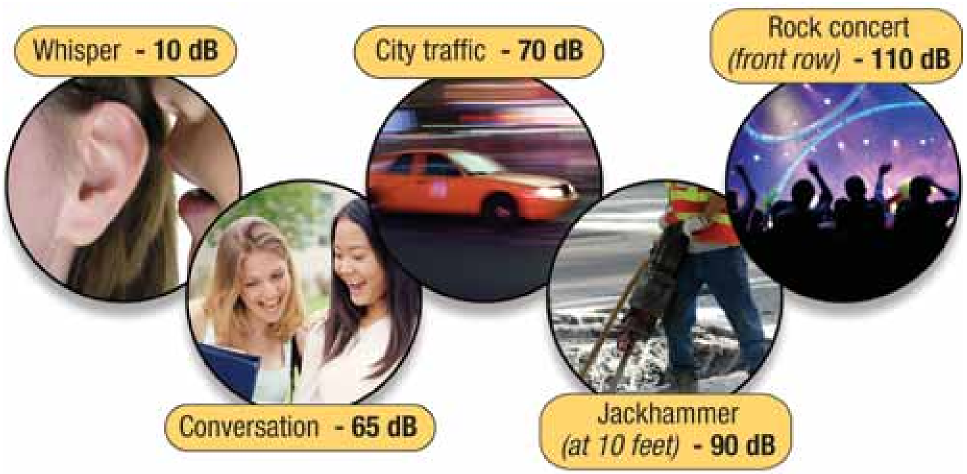


Figure 18.20: *At the same temperature, higher pressure contains more molecules per unit of volume than lower pressure.*

Properties of sound

Pitch The **pitch** of a sound is how we hear and interpret its frequency. A low-frequency sound has a low pitch, like the rumble of a big truck or a bass guitar. A high-frequency sound has a high pitch, like the scream of a whistle or siren. The range of frequencies humans can hear varies from about 20 hertz to 20,000 hertz.

Loudness The *loudness* of a sound is measured in decibels (dB). The *decibel* is unit used to express relative differences in the loudness of sounds. The *decibel scale* compares the loudness of sounds. Most sounds fall between zero and 100 on the decibel scale. The diagram below compares the loudness of some sounds on the decibel scale.



frequency spectrum Why is it easy to recognize one person's voice from another, even when people are saying the same word? The reason is that voices have different mixtures of frequencies. A *frequency spectrum* is a graph showing the different frequencies present in a sound. Loudness is on the vertical axis and frequency is on the horizontal axis. Figure 18.21 shows the frequencies of the voices for three individuals saying "hello."

VOCABULARY

pitch - how humans hear and interpret the frequency of sounds.

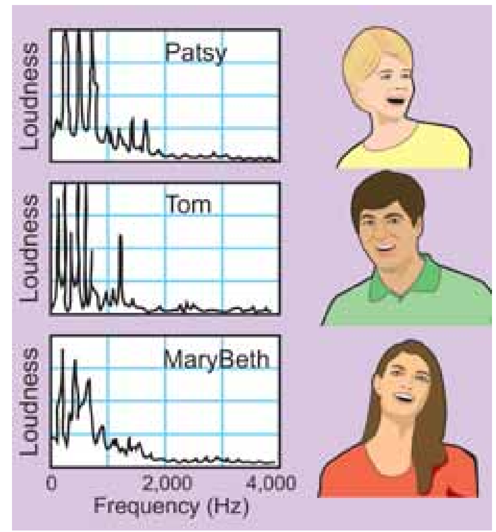
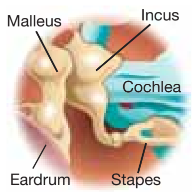


Figure 18.21: *The frequencies in three people's voices as they say the word "hello."*

How the ear works

The outer ear The parts of the ear are shown in Figure 18.22. The *outer ear* helps collect sound waves and directs them into the middle ear. Some mammals can move their outer ears to detect the direction of sound. You must turn your head. The outer ear funnels sound waves into the ear canal which leads to the middle ear.

The middle ear The *middle ear* is an air-filled cavity that consists of the eardrum and three tiny, interconnected bones: the *maleus*, *incus*, and *stapes* (shown left). The *eardrum* is a tightly stretched membrane that vibrates as the sound wave reaches it. The eardrum vibrates at the same frequency of the sound wave. Being connected to the maleus, the movements of the eardrum set the maleus, incus, and stapes into motion at the same frequency of the sound wave.



The inner ear The stapes is connected to the cochlea of the inner ear. The inner ear has two important functions: providing our sense of hearing and our sense of balance. The three semicircular canals near the cochlea are also filled with fluid. Fluid moving in each of the three canals tells the brain whether the body is moving left-right, up-down, or forward-backward. The **cochlea** is a tiny fluid-filled cavity in the inner ear that contains nerve endings essential to hearing.

The cochlea The stapes vibrates against the cochlea. Fluid in the spiral of the cochlea vibrates and creates waves that travel up the spiral. The spiral channel starts out large and gets narrower near the end. The nerves near the beginning respond to lower-frequency sound. The nerves at the small end of the channel respond to higher-frequency sound. Neurons in the cochlea convert the waves into nerve impulses and send them to an area of the brain that interprets sound.

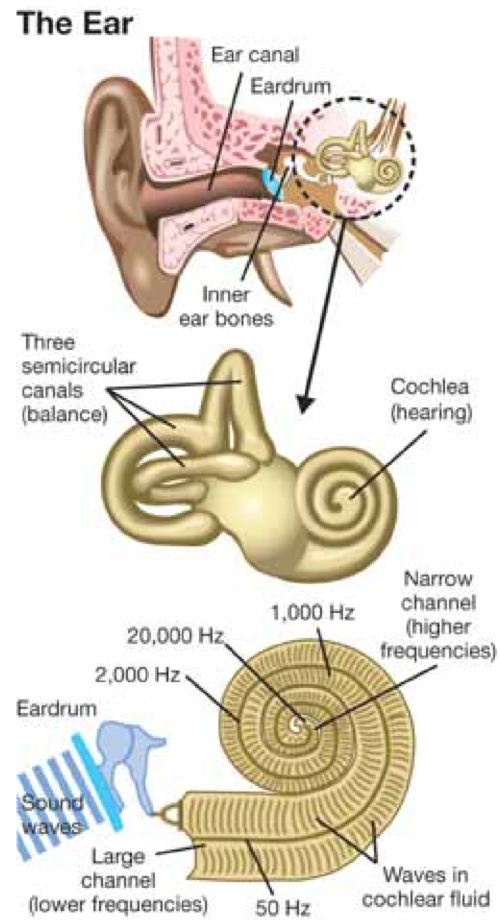


Figure 18.22: *The parts of the human ear.*

VOCABULARY

cochlea - a spiral-shaped, fluid-filled cavity of the inner ear that contains nerve endings essential to hearing.

18.4 Section Review

1. What is a wave? Why is sound a wave?
2. Explain why sound waves are described as pressure waves.
3. Two containers of equal volume are stored at the same temperature. Container A contains air under higher pressure than the air in container B. Which container has more molecules of air?
4. What is the frequency of a wave? What is the unit of frequency?
5. Which has a higher pitch, a bass guitar or a screaming voice?
6. What is a decibel? How are decibels used?
7. Based on experience, arrange the following sounds from lowest to highest on the decibel scale:
    a. a library
    b. a school band concert
    c. a barking dog from 10 feet away
    d. a whisper
8. Match each structure of the ear to its function:

Structure	Function
1. stapes	a. converts sound waves to vibrations
2. cochlea	b. transfers vibrations from ear drum
3. outer ear	c. vibrates against the cochlea
4. ear drum	d. gathers sound waves
5. maleus	e. directs sound waves to the ear drum
6. semi-circular canals	f. help you stay in balance
7. ear canal	g. contains a fluid that vibrates

SOLVE IT!

Light waves have very small wavelengths that are measured in nanometers. A nanometer is one-billionth of a meter. The wavelength of sound waves is measured in meters. The frequency of a wave is inversely related to its wavelength. Answer the questions below:

1. Which have higher frequencies, light waves or sound waves?
2. Arrange the following frequencies from longest to shortest wavelength: 500 Hz, 10 Hz, 20,000 Hz, 55 Hz.

PHYSICS CONNECTION

Keeping Things in Focus

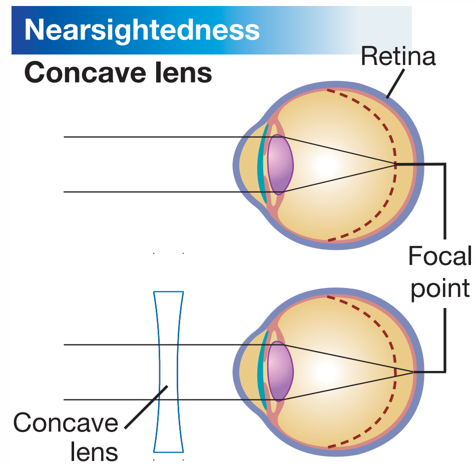
So gradually that you might not have noticed, you find you have trouble reading numbers or writing on the classroom chalkboard. Or a friend points to a sign down the hall, but you cannot quite make out what it says. What is happening? Maybe you are becoming nearsighted.

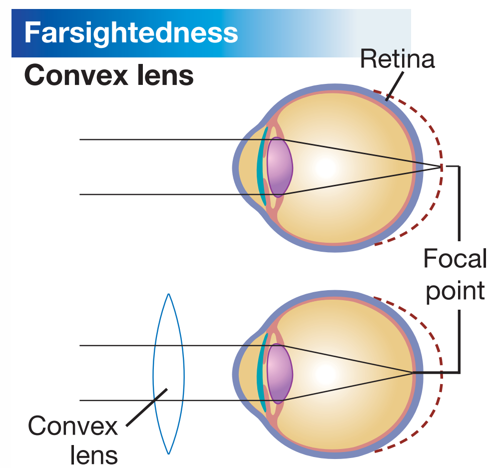
Nearsightedness is common, affecting one in four people, and most often developing during school age and adolescence. If you are nearsighted, objects near you are clear, but objects at some distance are blurry. This occurs when light rays entering the eye are focused imperfectly, either because the eyeball is too long or because the cornea bulges. In the normal eye, light rays passing through the cornea and lens are focused perfectly, reaching the retina and creating clear images.

Science has made it easy to correct nearsightedness with glasses or contact lenses. The lenses may have to be changed a few times as a child grows, but nearsightedness usually stabilizes in a person's early twenties.

Vision is an amazing process. Light reflects off objects all around us. When we look at an object, reflected light enters our eyes. That light is focused and hits the retina, the innermost layer of the eye, the light-sensing area at the back of the eye. In the retina, light energy is converted to electrical impulses that our brains interpret as vision.

When vision is normal, the light image is in focus when it hits the retina. In the eyes of a nearsighted person, the image focal point is in front of the retina. The image is out of focus by the time it reaches the retina. The brain sees a fuzzy image. Corrective lenses change the focal point of the image so that it is in focus when it reaches the retina. Wearing glasses or contacts, nearsighted people can see as clearly as people with normal vision.





Looking at farsightedness

You have almost certainly seen someone - your teacher, a parent or grandparent - reach for their glasses to read the fine print on something. If a person has trouble focusing on objects that are close, that person is farsighted. Many people become farsighted later in life. The eye shortens, changing the focal point of light entering the eye. The light entering the eye is focused behind the retina. Farsighted people have difficulty clearly seeing objects that are close; they look fuzzy or blurry. This is the opposite of what people who are nearsighted experience, when they are unable to focus clearly on objects in a distance.

Both conditions can be remedied with corrective lenses. With a nearsighted person, a concave lens, or a lens that curves inward, bends the light so that the focal point is in front of the lens. When the image reaches the retina, it will be in focus. With someone who is farsighted, a convex lens, or a lens that curves outward, bends the light so that the focal point is behind the lens. Here, too, when the image reaches the retina, it will be in focus.

Reading the "E"

Dr. F. Todd Perzy, an optometrist, uses a variety of tests to examine people's eyes. One of the most common tests is reading an eye chart. With the lights dimmed, the patient focuses on a large target, like the "E" on the chart. The doctor shines a light into the patient's eyes and flips lenses in a machine positioned in front of each eye. Depending on how the light reflects from the patient's eyes, Dr. Perzy can start to determine the necessary corrective measures.

An eye doctor, be it an optometrist or an ophthalmologist, also checks the overall health of the eye. He shines light into the patient's eye and examines each part from front to back.

Advances in vision correction

Glasses and contact lenses are no longer the only way to correct vision. Today, LASIK (an acronym for laser-assisted in situ keratomileusis) is the most popular. This eye surgery reduces or eliminates the need for glasses in people who are nearsighted or farsighted. Since 1995, approximately 3 million Americans have had some type of laser eye surgery. But even with the advancements in laser surgery, more than half the people in the United States still wear some type of corrective lens.

Questions:

1. Explain what happens to images in the eye when a person is farsighted.
2. Explain what happens to images in the eye when a person is nearsighted.
3. What is the difference between a concave lens and a convex lens?

Chapter 18 Connection

Human Ear Model

CHAPTER ACTIVITY

Ears are truly amazing organs. The ear picks up mechanical sound waves (vibrating air molecules) and translates the vibrations into signals that the brain can understand. In this activity you will build a model of the ear. Then, you will figure out how the model works. Finally, you will relate the parts of your model to the parts of a human ear.

To build your model, you will need:

- 2 plastic cups
- 1 empty potato stick can
- 1 balloon
- 1 index card
- 1 small lightweight ball (Styrofoam or hollow plastic)
- 1 party noisemaker

What you will do

1. Carefully cut off the bottom of the potato stick can so the can is open at both ends.
2. Cut off the neck of the balloon and stretch it over one end of the can; secure with tape. Make sure the balloon is stretched as tightly as possible.
3. Cut a strip of index card that is 0.5 cm wide.
4. Tape one end of the index card strip to the balloon-covered end of the can
5. Tape the other end of the index card strip to the lightweight ball.
6. Tape the entire can/balloon/paper/ball assembly to an upside-down cup.
7. Fill the second cup with water and place it under the ball so the ball floats on top of the water.
8. To operate your ear model, insert the noisemaker into the can from the open end so that it is very close to the balloon covering, but not touching it or any part of the can. Without moving any part of the model, blow into the noisemaker and watch what happens to the floating ball.

Applying your knowledge

a. What causes the floating ball to move?
b. Make a sketch of your ear model and label the parts of the model that represent the: outer ear, eardrum middle ear bones, inner ear/cochlea.
c. Do Internet or library research on three different causes of hearing loss.
d. Do Internet or library research on new devices called cochlear implants that allow hearing impaired people to hear sounds for the first time. How do the implants work?

Chapter 18 Assessment

Vocabulary

Select the correct term to complete the sentences.

central nervous system	cerebellum	image
cone cells	cerebrum	medulla
frequency	cochlea	motor nerves
nerve impulse	optic nerve	optics
peripheral nervous sys-	photoreceptors	pitch
tem	pupil	real image
rod cells	sensory nerves	virtual image
wave	withdrawal reflex	

Section 18.1

1. The three parts of the brain are: the _____, which controls involuntary actions; the _____, which controls voluntary movements and the senses; and the _____, which provides feedback on the position of the body.
2. A wave of chemical and electrical activity transmitted between neurons is called a _____.
3. _____ send nerve impulses through wire-like nerve fibers to the spinal cord, while _____ control muscle contractions.
4. An example of a _____ is when someone pulls their hand back from a hot plate.
5. The two divisions of the nervous system are the _____, which is the command center, and the _____, which is the "information highway."

Section 18.2

6. The iris opens and closes to change the size of the _____ depending on the amount of light available.
7. The _____ carries nerve impulses from the eyes to the brain.
8. _____ are photoreceptors that respond to color, while _____ are photoreceptors that respond to light intensity.
9. Even though the _____ formed in the retina is upside down, your brain interprets it as right side up.
10. The retina contains light sensitive cells called _____.

Section 18.3

11. A mirror creates a _____, whereas a converging lens can create a _____.
12. The study of how light behaves is called _____.

Section 18.4

13. _____ is measured in Hertz (Hz).
14. The _____ is how humans hear and interpret the frequency of sounds.
15. Your ear detects sound _____.
16. Neurons in the _____ convert waves into nerve impulses and send them to the brain.

Concepts

Section 18.1

1. Which division of the nervous system includes these parts?
   a. brain
   b. nerves throughout the body
   c. spinal cord
2. What are the three parts of a neuron?
3. Which of these is not a withdrawal reflex?
   a. pulling hand back from a hot pan on the stove
   b. taking foot out of cold pool water
   c. shivering on a cold day at the bus stop
   d. none of the above

4. What is the difference between sensory and motor neurons?
5. Put the following events of a withdrawal reflex in the correct order:
   a. inside of the cell membrane becomes positively charged
   b. sensory nerves in skin receive stimuli
   c. inside of the cell membrane becomes negatively charged again compared to the outside
   d. chemicals are released to pass on the nerve impulse to the neighboring neuron
   e. impulse travels down the axon to the end
   f. other channels open to let out positively charged particles
   g. stimulus causes cell membrane to open channels to let in positively charged particles
6. Certain drugs inhibit the release of chemicals from the axons of nerve cells. How may these drugs affect the transmission of nerve impulses?
7. Identify the correct part of the brain for each description:
   a. largest part
   b. controls the spinal cord
   c. keeps body balanced
   d. located under the back half of the cerebrum
   e. divided into two halves called hemisphere
   f. located in front of the cerebellum
   g. controls voluntary movement
   h. receives input from the heart and blood vessels
   i. controls the senses
8. Infer which part of the brain is responsible for coughing and sneezing. Explain your choice.
9. What symptoms might indicate that a person's cerebrum has been injured?
10. Explain why injuries to the medulla are often fatal.
11. A stroke results from a clot in the brain that typically results in paralysis. If a person was unable to move their left arm and left leg after a stroke, predict which side of the brain the clot most likely occurred in. Explain your prediction.

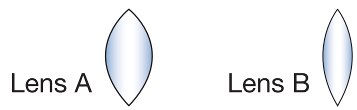
Section 18.2

12. How is light critical to vision?
13. Explain how light travels through the eye.
14. What happens to the iris and the pupil in these situations?
    a. a person leaves the movie theater on a sunny afternoon
    b. a person goes inside after soccer practice on a sunny morning
    c. the light is turned on when a person is napping in a dark room
15. How does your eye focus on objects?
16. Which color has the most energy? Which color has the least energy?
17. What are the two types of photoreceptors? Describe their functions.
18. Which works better in dim light - rods or cones? Explain.
19. Why is color vision best at the center of the field of view?
20. What is the additive color process?
21. Which of these is not a primary color?
    a. white
    b. green
    c. blue
    d. red

22. Explain how the design of traffic lights helps people with color blindness.

Section 18.3

23. Which of the following terms relates to optics?
    a. image
    b. focal point
    c. light rays
    d. all of the above
24. Explain how a camera captures an image.
25. Of the lenses shown to the right, which has the shorter focal length?



26. What is an optical system? Describe their two functions.
27. Why does a lens give a brighter image than the hole in a pinhole camera?
28. What are the two types of telescopes? Explain the difference.

Section 18.4

29. How are sound and light similar? How are they different?
30. Describe how sound is created.
31. What are two properties of sound? Describe each property.
32. How can you recognize different people's voices?
33. Why is being able to move their ears a helpful adaptation for some mammals?
34. Explain why a person should never stick a sharp object in their ear.
35. Why can an infection in the inner ear cause a person to lose their balance?

Math and Writing Skills

Section 18.1

1. Write a short story that has three examples of withdrawal reflexes. Do not mark your examples so that a classmate may try to identify the examples in your story.
2. The average human brain weighs 1.3 kilograms. If 1 kilogram is equivalent to 2.21 pounds, how many pounds does the average human brain weigh?
3. A nerve impulse can travel at the speed of 120 kilometers per second. Electricity can travel at 300,000 kilometers per second. How many times faster do electric impulses travel than nerve impulses?

Section 18.2

4. In the average eye, 130 million of the photoreceptors in the eye are rod cells, while 7 million of the photoreceptors are cone cells. What percent of photoreceptors are rod cells? What percent are cone cells?
5. If the brain evaluates all 137 million dots created by photoreceptors every fifteen seconds, how many times does the brain scan all the dots in a minute? In an hour? In a day?

Section 18.3

6. Look around your house and school to find examples of how optics affect your daily life. Write a paragraph describing the ways that optics impact you each day.
7. Write a short story that includes at least five examples of real and virtual images. Do not indicate your examples in the story so that a classmate can try to identify your examples as real or virtual images.
8. Choose an optical system to describe in detail including how it works.

Section 18.4

9. Write short play that explains how a sound wave travels through the ear. Include how the sound wave affects the different parts of the ear.
10. Imagine that you are a town representative that is in charge of setting local noise level laws. Propose what you believe would be a reasonable maximum decibel limit. Explain your proposal.
11. A noise creates 10,000 vibrations in 2 seconds. What is the frequency of this sound in Hertz?
12. The speed of sound is 340.29 m/s. The speed of light is 299,792,458 m/s. Given these speeds, how much faster is light than sound? How does this explain why you see lightening before you hear thunder?

Chapter Project

Color models

Our eyes work according to an *additive color process*. Three photoreceptors (red, green, and blue) in the eye operate together so that we see millions of different colors. Color printers work according to a *subtractive color process*. Three different pigments or inks (cyan, magenta, and yellow) combine to make millions of different colors. In this project, you will combine cyan, magenta, and yellow clay or paint to produce the colors red, blue, and green. You will need:

- Polymer clay or tempera paint in the colors cyan, magenta, and yellow
- One sheet of construction paper or poster board
- Paintbrush and water (if using paint)
- Ruler and pencil

1. Create a blank color chart on your construction paper or poster board like the one below. DO NOT write the words in the boxes.

magenta	Mix magenta and cyan, with more magenta than cyan	Mix equal parts of magenta and cyan	Mix cyan and magenta, with more cyan than magenta	cyan
yellow	Mix yellow and magenta, with more yellow than magenta	Mix equal parts of yellow and magenta	Mix yellow and magenta, with more magenta than yellow	magenta
cyan	Mix cyan and yellow, with more cyan than yellow	Mix equal parts of cyan and yellow	Mix cyan and yellow, with more yellow than cyan	yellow

2. On the boxes of the table that contain a color name, paint that box with the pure color of paint or fill the box with that color clay by pressing the clay firmly onto the paper.
3. In the other boxes of each row, create a mixture according to the instructions in each box and paint or press the clay into the appropriate box.
4. When you look at the middle boxes, you should see one that is red, one that is blue, and one that is green. If you do not see these colors, you will have to experiment with different ratios of one color to another to achieve the pure red, blue, and green. If your magenta is more intense than your cyan, for example, you might not be able to mix equal parts to achieve a sharp blue color. Mix your paint on a different piece of paper before you use it to paint your final boxes. If you are using clay, work the colors together well to achieve your final colors before you press it onto the final grid.
5. On the back of your color chart, write a paragraph that summarizes what you have learned about the subtractive color process by doing this project.